Solving the problem of switching from one track gauge to another in the context of the requirements of interoperability specifications for classical infrastructure

Maxim Arbuzov, Volodymyr Andrieiev*, and Stanislav Kosturechko

Ukrainian State University of Science and Technology, Department of Transport Infrastructure, 49010 Dnipro, Lazaryana Street 2, Ukraine

Abstract. The article discusses issues related to solving the problem of switching from one gauge to another. A progressive solution to the problem of different track gauges is the use of a combined gauge design. The combined track solves the problems of overloading, downtime, and wheel set problems. The design of the combined gauge has set new challenges for track infrastructure workers and scientists. The first task is the strength of the combined track structure. The second task is the stability of the combined track plates. The third task is to lay switches in the combined track and determine the permissible train speeds.

1 Introduction

The process of European integration requires studying and applying the regulatory documents of the European Union. The implementation of European standards is now widely used in practice. An important aspect is the interoperability of technical systems.

Today, railroad employees are studying the Technical Interoperability Specifications for classical infrastructure and its maintenance, in particular Commission Regulation (EU) No 1299/2014 of November 18, 2014 on technical specifications for interoperability relating to the ‘infrastructure’ subsystem of the railway system in the European Union [1]. This issue addresses the problems of switching from one gauge to another. The gauge is measured between the working faces of two rails. The rolling stock of Polish railways is designed for a track gauge of 1535 mm. Ukrainian railways have a track gauge of 1520 mm. Polishing rolling stock cannot enter Ukrainian railways, and Ukrainian rolling stock cannot enter Polish railways. Therefore, there is a problem of technical incompatibility of gauge. This problem is solved by various methods.

To transport goods from one country to another that have different track gauges, transshipment is used. It is convenient to reload cargo in containers. This technology forms a containerized cargo transportation system and does not solve the problem of different track gauges.

Previously, there was a system of sliding SUW wheelsets. This system was aimed at solving the problem of different track gauges. However, the complexity of operating and repairing the SUW system has led to the fact that it is not used today. The solution to the track gauge problem has created a safety issue in rail transport.

2 Combined track work

The system of replacing bogies under the cars is used. The car is lifted, bogies designed for a track gauge of 1520 mm are rolled out, and bogies designed for a track gauge of 1435 mm are rolled in. There are problems with the lifting mechanisms and the speed of such operations. This technology takes a lot of time. It is not possible to increase the speed of the lifting mechanisms. Increasing the number of lifting mechanisms is a financially expensive solution.

For the transportation of goods from one country to another with different gauge standards A progressive solution to the problem of different track gauges is the use of a combined track structure (Figure 1). A rail and sleeper grid made of four rails, sleepers and fasteners is laid within one subgrade. One pair of rails has a track gauge of 1520 mm, the other pair of rails has a track gauge of 1435 mm. The combined track solves all of the above problems of overloading, downtime, and wheel set problems.

Fig. 1. Section of combined 1520 and 1435 mm rail gauge

The total length of the combined rail gauge (1520 mm and 1435 mm) on the Lviv Railway is 153.4 km. Such a track is laid on the sections State border - Mostiska-II -
Rodatychi, State border - Chop - Batyevo, State border - Yahodyn - Kovel. These sections are part of the international transport borders (Krytskyy No. 3 and 5, Hradsk - Odesa).

Two double-track electrified railway lines connecting Lviv with European countries end in sections with combined gauge. The first of these lines, 84 km long, passes through Mostyska-II station and is the shortest connection to Poland, Slovakia, the Czech Republic, Germany and other Central European countries, as well as Scandinavia. The railway line Lviv - Mostyska-II - State Border is a part of the third trans-European transport corridor (Berlin - Wroclaw - Przemysl - Lviv - Kyiv) and at the same time a part of the international line E30 covered by the AGC agreement.

The second line, 266 km long, passes through Chop and connects Ukraine with Slovakia, Bulgaria, Romania, and other countries in Central and Southern Europe.

However, the design of the combined track posed new challenges for track infrastructure workers and scientists. The first challenge is the strength of the combined track structure. The second task is the stability of the combined track plates. The third task is to lay switches in the combined track and determine the permissible train speeds.

**Permissible temperature drop from the rail strength condition.**

For conventional jointless track, the permissible temperature drop from the condition of rail strength is given in the "Technical instructions for the arrangement, laying, repair and maintenance of jointless track on the railways of Ukraine" [2] for different rolling stock units, different track layouts, rail types, and different speeds [9]. The values \( \Delta t_p \) are determined for a jointless track with non-hardened rails of the P65 type of the first service life on reinforced concrete sleepers and crushed stone ballast. For hardened rails of the P65 type of the first service life, the value of \( \Delta t_p \) is increased by 20°C, and for old rails on the main tracks it is reduced by 5°C [2]. The value of "5°C" is actually variable and depends on the amount of stress in the rail sole due to the action of the rolling stock. This value is taken as the largest value that goes into the safety margin.

When determining the permissible temperature drop from the rail strength condition for a combined buttless track, the first problem is the lack of "Rules for calculating the combined track for strength". Today, for the combined track, it is necessary to clarify the methods of calculating stresses at the edge of the rail sole, at the edge of the rail head, on the sleeper under the substrate, in the ballast under the sleeper, and on the main subgrade. These studies require both the development of a new model of interaction between rolling stock and track and experimental trips of different types of rolling stock to verify the developed theoretical positions and determine the elastic modulus of the subgrade.

But even in the absence of the "Rules for calculating the strength of combined track", it is obvious that

1) the rail and sleeper grid of a combined track is more rigid than a conventional track;
2) for two rails loaded by the action of rolling stock wheels, the subgrade base takes the form of a frame due to the presence of two more rails attached to the sleepers;
3) the elastic modulus of the subgrade U for the combined track is higher than for the conventional track.

According to the "Rules for Calculating Railway Track for Strength and Stability" [3], the average value of the elastic modulus of the subgrade for conventional track for the KPP-5 in winter is 75.6 MPa.

The operation of the subgrade in the area of the connecting part of the turnout is similar to the operation of the subgrade of a combined track, since there are two loaded and two free rails attached to a common bar. As a first approximation, the elastic modulus of the subgrade of the combined track is the elastic modulus of the subgrade of the connecting part of the turnout for winter conditions with reinforced concrete bars. So, we assume that the elastic modulus of the subgrade of the combined track base \( U = 95.3 \text{ MPa} \) [3].

Let's perform a strength calculation for a conventional (2-strand) track and a combined (4-strand) track. According to calculations \( \Delta t_p \) for the combined track on \( 2^\circ \text{C} \) is greater than \( \Delta t_p \) for the conventional track.

Consequently, for a combined jointless track, \( \Delta t_p \) should be increased by 2°C compared to the values given in the "Technical instructions for the arrangement, laying, repair and maintenance of jointless track on the railways of Ukraine" [2].

Let's perform calculations using computer modeling to confirm that the stresses in the rails of the jointed track are lower than in the conventional track.

The strength and stability of a railroad track is determined in accordance with regulatory requirements [3]. However, the methodology for calculating a railroad track does not provide for a four-rail structure. Therefore, this problem must be solved by means of finite element modeling. The finite element method (FEM) is the main method of modern structural mechanics and is the basis of the vast majority of modern software packages, including the Slid Edge program.

To verify the operation of the model of a conventional track with a width of 1520 mm in Solid Edge over a wide range of vertical loads, calculations were performed for different values of the design force \( P_{roz} \). The study of the stresses in the rail head due to load changes in the PUT program, which is based on the methodology of the normative document [3], and Solid Edge is shown in Table 1. The results show that modeling in Solid Edge is applicable.

**Table 1. Study of stresses along the rail head axis**

<table>
<thead>
<tr>
<th>( P_{roz} ), kN</th>
<th>( \sigma_{Solid \text{ Edge}} ), MPa</th>
<th>( \sigma_{PUT} ), MPa</th>
<th>Error, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>119,8</td>
<td>65,39</td>
<td>67,21</td>
<td>2,7</td>
</tr>
<tr>
<td>129,4</td>
<td>70,63</td>
<td>72,86</td>
<td>3</td>
</tr>
<tr>
<td>139,1</td>
<td>77,06</td>
<td>78,62</td>
<td>1,9</td>
</tr>
<tr>
<td>149,3</td>
<td>81,49</td>
<td>84,75</td>
<td>3,8</td>
</tr>
<tr>
<td>157,4</td>
<td>85,89</td>
<td>89,56</td>
<td>4</td>
</tr>
</tbody>
</table>

When modeling the combined gauge (Figure 2), the same simplifications were used as for the conventional 1520 mm gauge. The differences between the models are...
in the type of sleepers: for the 1435 mm and 1520 mm gauge, 2850 mm long Sh2C-1 sleepers were used, and the ballast dimensions were changed. The length of the model remained unchanged.

\[ \Delta t_{e} = \frac{P_{e}^c}{k_{e}} \]  

\( \Delta t_{e} \) – permissible temperature force from the stability conditions of a conventional jointless track determined from the expression

\[ P_{e}^c = \frac{\rho_{t}}{k_{e}} \]  

\( P_{e}^c \) – the critical temperature force at which a conventional jointless track is ejected;

\( k_{e} \) – permissible stability factor, 1.5.

The permissible temperature force from the stability conditions of the combined jointless track is determined from the expression

\[ P_{e} = \frac{\rho_{t}}{k_{e}} \]  

\( P_{e} \) – the critical temperature force at which the combined jointless track is ejected;

\( k_{e} \) – permissible stability factor, 1.5.

Then you can write down

\[ [\Delta t_{e}] = \frac{\rho_{t}}{P_{t}} \cdot [\Delta t_{e}] \]  

Let us choose a method for calculating the critical temperature force.

The closing temperature force, at which the ejection occurs, has been determined by many authors of the theory of operation of a continuous track: K.M. Mishchenko, A.A. Kryvobodrov, S.P. Pershin, O.Y. Kogan, S.I. Morozov, M.F. Verigo, V.I. Novakovich, V.O. Grishchenko, E.M. Bromberg, V.G. Albrecht, M.P. Vinogorov, Z.A. Kreinin, E.I. Danilenko, M.I. Karpov, O.M. Patlasov, V.P. Shramenko. However, the expressions where the closing force is determined through the stiffness of the rail and sleeper lattice are complex. Thus, according to the formulas of K.N. Mishchenko [4] according to K. Eswald [3], the critical temperature force is determined by the formula

\[ q = \frac{P_{t}^c \sqrt{1 + \frac{4\rho_{t}}{7.8 \tau_{0} E I_{p}}} + \rho_{t}}{l} \]  

\( q \) – the longitudinal resistance to the longitudinal movement of the rail and sleeper grid;

\( \rho_{t} \) – the linear resistance to the transverse movement of the rail and sleeper grating;

\( l \) – the wavelength of the ejection distortion;

\( E \) – the elastic modulus of rail steel;

\( l_{paw-2} \) is the moment of inertia of the rail and sleeper grid in the horizontal plane;

\( F \) – the cross-sectional area of the rail;

\( \tau_{0} \) is the distributed resistance to lateral movement of sleepers;

\( f_{0} \) – initial inequality.
$R$ – curve radius.

The Sh2S sleeper of 1520 mm and 1435 mm combined gauge with KPP-5 type fastening weighs 368 kg, which is 1.4 times heavier than the Sh1 sleeper. The bearing area of the Sh2S sleeper is 1.08 times larger than that of the Sh1 sleeper. However, the laying pattern of Sh2S sleepers is 1520 pcs/km, which is 1.21 times less than that of conventional buttless track. The distributed resistance of sleepers to lateral displacement is known to be formed by both mass and grip. Therefore, as a first approximation, the distributed resistance $\tau_0$ of sleepers of a combined track to lateral displacement is assumed to be equal to the distributed resistance to lateral displacement of sleepers of a conventional track.

For the most common modern standard designs of jointless track and operating conditions, it is possible to plot the dependence of the permissible temperature increase of rail plates on the radius of the curve (Figure 3). Also in Figure 3 also shows graphs of the dependence of the permissible temperature increase of rail plates $[\Delta t_c]$ on the radius of the curve, which were built according to the Technical Guidelines [5], according to calculations by Bromberg E.M. and Pershin S.P.

\[\Delta t_c = \frac{E_{\text{co}}}{E_{\text{coz}}} \cdot \left(\Delta t_{\text{cz}}\right)^2\]  

(Eq. 7)

$E_{\text{co}}$ – horizontal stiffness of the combined track;
$E_{\text{coz}}$ – horizontal stiffness of a conventional track.

The horizontal stiffness of the rail and sleeper grid was determined experimentally.

Experimental studies were conducted to determine the horizontal lateral stiffness of conventional and combined track according to the developed methodology.

Studies of the horizontal lateral stiffness of conventional jointless track were carried out on a 9483 mm long rail and sleeper grid, fasteners of the KB-65 type, and rails of the P65 type. The rail and sleeper grid was raised at points located 340 mm from the rail ends. The number of sleepers of type Sh1 is 18 pcs.

As a result of lifting from its own weight, the rail and sleeper grid was deformed, forming a deflection arrow (Figure 4).
The rail and sleeper grid was raised at points 760 mm from the rail ends. The number of sleepers of the Sh2C type is 19 pcs.

The average value of the bending arrow of the rail and sleeper grid of the conventional track is 142.5 mm, and the combined one is 235.9 mm.

Studies of the horizontal lateral stiffness of conventional jointless track with KPP-5.2 type fastening were carried out on a 12495 mm long rail and sleeper grid, rail P65. The rail and sleeper grid was raised at points located 590 mm from the rail ends. The number of sleepers of type Sh1 is 23 pcs.

The average bending arc of the rail and sleeper grid of a conventional gauge with a KPP-5.2 type fastener is 495.7 mm.

Experimental measurements of the stiffness of the rail and sleeper lattice are presented in Table 2.

Table 2. Calculation of the stiffness of rail and sleeper gratings

<table>
<thead>
<tr>
<th>Type RSG</th>
<th>EI, kN/sm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal KB-65</td>
<td>40207421</td>
</tr>
<tr>
<td>Combined</td>
<td>78166162</td>
</tr>
<tr>
<td>Normal KPP-5.2</td>
<td>30379409</td>
</tr>
</tbody>
</table>

Based on the data obtained experimentally on the stiffness of the rail and sleeper grid of a conventional jointless track and a combined jointless track, we determine the stiffness of the rail and sleeper grid of a conventional gauge with a KPP-5.2 type fastener as 495.7 mm.

Thus, Table 3 shows the permissible temperature increases of rail plates of the combined jointless track with KPP-5 fastening [6] and 1520 pcs/km sleeper pattern, determined experimentally.

Table 3: Permissible temperature increases for rail plates of combined jointless track with fastening KPP-5

<table>
<thead>
<tr>
<th>Rail Type</th>
<th>Permissible temperature increase of the rail plates, taking into account the stability of the combined track ( [\Delta t_c] ), °C</th>
<th>in curves of radius, m</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>in a straight line</td>
</tr>
<tr>
<td>P65</td>
<td></td>
<td>2000</td>
</tr>
<tr>
<td>1520</td>
<td></td>
<td>2000</td>
</tr>
<tr>
<td>40</td>
<td></td>
<td>2000</td>
</tr>
<tr>
<td>37</td>
<td></td>
<td>2000</td>
</tr>
<tr>
<td>35</td>
<td></td>
<td>1200</td>
</tr>
<tr>
<td>50</td>
<td></td>
<td>1200</td>
</tr>
<tr>
<td>60</td>
<td></td>
<td>1200</td>
</tr>
<tr>
<td>80</td>
<td></td>
<td>1200</td>
</tr>
<tr>
<td>1000</td>
<td></td>
<td>800</td>
</tr>
<tr>
<td>1200</td>
<td></td>
<td>600</td>
</tr>
<tr>
<td>1435</td>
<td></td>
<td>500</td>
</tr>
<tr>
<td>1900</td>
<td></td>
<td>400</td>
</tr>
<tr>
<td>2000</td>
<td></td>
<td>400</td>
</tr>
<tr>
<td>2350</td>
<td></td>
<td>350</td>
</tr>
<tr>
<td>3000</td>
<td></td>
<td>300</td>
</tr>
</tbody>
</table>

The maximum speeds allowed on the Ukrainian railways network for passenger and freight trains depend on the track design and types of rolling stock. In this case, the speed of passenger and freight trains on the side tracks on turnouts made of P65 and P50 rails with 1/11 grade crossbars should not exceed 40 km/h [7].

The permissible speeds of trains in curves are established based on the condition of not exceeding the norms of permissible unburned accelerations at the design parameters of the track. The calculated permissible unburned acceleration for passenger trains, provided that the passengers ride comfortably, is 0.7 m/s². The nominal value of the unburned acceleration for freight trains, subject to technical and economic indicators, should be within ±0.3 m/s².

The permissible speeds of trains on switches to the lateral direction are determined as for a track of the same design on a run in a curve of the same radius as the radius of the transfer curve or cross curve, taking into account the absence of an outer rail elevation.

There is no outer rail elevation on the 1520 mm and 1435 mm gauge intertwining (Dn 917 and Dn 918). The permissible speed of trains in the sidings, provided that the norms of permissible accelerations are not exceeded, is determined by the requirements of the regulatory document [7]:

Under this condition, the sidingspeed is:

\[ V_{a=0.3} = 27.2 \text{ km/h} \]
\[ V_{a=0.7} = 41.5 \text{ km/h} \]

Permissible speed when acceleration changes

\[ V = 3.6\sqrt{bR_{min}\psi} \]

\( b \) – the crew's estimated base, is accepted 17 m,
\( R_{min} \) – radius of the curve (for Dn 917 is 190 m, for Dn 918 - 200 m)
\( \psi \) – for freight - 0.3 m/s³, for passenger - 0.6 m/s³.

\[ V_{\psi=0.6} = 44.89 \text{ km/h at } R_{min}=190 \text{ m} \]
\[ V_{\psi=0.3} = 35.6 \text{ km/h at } R_{min}=190 \text{ m} \]
\[ V_{\psi=0.3} = 36.24 \text{ km/h at } R_{min}=200 \text{ m} \]

The speed in the forward direction is 120 km/h, as in turnouts of grade 1/11.

Analyzing the data obtained in the calculations, we conclude that the permissible speeds of trains on the intertwined tracks (Dn 917 and Dn 918) are –

\[ V_{direct} = 120 \text{ km/h} \]
\[ V_{side \text{ pass}} = 35 \text{ km/h} \]
\[ V_{side \text{ cargo}} = 25 \text{ km/h} \]
3 Conclusion

Thus, in the context of the implementation of European standards, a promising solution to the problem of switching from one track gauge to another is the use of a combined track. The calculations performed for the combined track confirm the strength and stability of the rail and sleeper grid and the set speeds of trains on switches.

References

5. Pravyla vyznachennia pidvyschennia zovnishnoi reiky i vstanovlennia dopustymych shvydkostei v kryvych dilianakh kolii [Text]: CP-0236. – Kyiv, 2011. [in Ukrainian]